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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

April 1966

GCA CORPORATION
GCA TECHNOLOGY DIVISION
Bedford, Massachusetts

SODIUM VAPOR EXPERIMENT

Quarterly Progress Report No. 3

Covering the Period
1 January 1966 - 31 March 1966

Prepared under Contract No. NAS5-3970

TABLE OF CONTENTS

I. INTRODUCTION

The purpose of this contract is to investigate the dynamics of the upper atmosphere through analysis of the motion of sodium vapor trails ejected from sounding rockets. Data are taken photographically from several widely separated sites. Triangulation is used to determine winds from the rate of motion of the trail, and densitometry measurements determine the growth rate and small-scale structure of the trail. Complete descriptions of the experimental and analytical methods are given in reports covering NASA contracts NAS5-215 and NASw-396. Theoretical studies of the dynamics of the upper atmosphere are directed toward formulation of models based on the observations. The first series of rocket firings occurred during November 1964 from Wallops Island and simultaneously from a ship at selected distances from Wallops Island. The objective of the series was to investigate the variation of the vertical wind structure at two places separated by different distances.

The results of the first series were seriously limited by vaporizer malfunction, but one set of trails separated by 180 km showed the winds to differ significantly above 120 km. Previous analysis of several up and down trails separated by a distance of about 50 km have shown no wind variations over that distance. Continuation of the study of horizontal variation of the vertical wind profile was an objective of a series of flights from Wallops Island during June 1965. Two vapor trails were ejected from rockets fired nearly simultaneously on different azimuths during the evening twilight of 22 June and the morning of 23 June. A fifth rocket ejected a trail of TMA at 2300 EST on 22 June to allow observations of the time variations of the winds.

The spatial separation of the simultaneous trails in June was not large and the differences in the wind profiles were small. The evening trails were separated by only 25 km, and the wind speed around 100 km was only about 30 m/sec. The trail separation and wind speed of the morning trails were greater than those of the evening trails. The TMA trail, because of poor rocket performance, did not reach the predicted altitude and faded very quickly, causing some loss of data in the 100 to 125 km region and reduced the accuracy of the data below that height. Thus, the information on spatial variations is limited. Much more information was obtained from the time-spaced trails. The low wind speeds during evening twilight had increased by a factor of 2 to 3 by 2300 EST (about 3 hours later) and the familiar spiral pattern had begun to form. The clockwise spiral was even more apparent over much of the height region by morning twilight and the whole pattern had been continually rotated through the night, as has been previously observed in other time sequences in January and July 1964. The observations should be more closely spaced in order that the exact nature of the changes may be determined. Such closely spaced observations were the purpose of the series of firings at Wallops Island in January 1966. The results of the January series are presented and discussed in this report.

II. ROCKET FIRINGS

During the night of 17-18 January 1966, five vapor trail payloads were successfully launched on Nike Apaches from Wallops Island. All launches occurred very close to the desired time and all payloads and vehicles performed satisfactorily. The vehicle performance was unusually good except for 14.264 which was low due to a short burning first stage. The firing schedule and performance of the series are shown in Table I.

The usual camera sites were established at Dover Air Force Base, Camp A. P. Hill, Andrews Air Force Base, and Dam Neck Naval Training Station. There were a few scattered clouds but generally all sites were clear throughout the firing period. All sites had standard 70 mm cameras and mounts, and a special lens with a speed of f-1.5 for the night trails: A K-24 camera with a 20-inch focal length lens was used at all sites except Dover to observe the small-scale structure on the trails around 100 km. A large aperture, 36-inch focal length camera was used at Dover. Generally, the equipment functioned well and good data were obtained at all sites.

TABLE I

SCHEDULE OF LAUNCHES
(January 1966)

NASA Vehicle Number	Launch Date	Time EST	Payload Type	Peak Alt. km	Alt. Region of Wind Data km
14.262 CM	17 Jan. 1966	1739	Alkali Vapor	207	85-170
14.263 CM	17 Jan. 1966	1932	TMA	205	92-134
14.264 CM	17 Jan. 1966	2100	TMA	167	92-131
14.265 CM	18 Jan. 1966	0012	TMA	207	91-135
14.266 CM	18 Jan. 1966	0631	Alkali Vapor	213	85-170

III. WIND DATA - JANUARY 1966 SERIES

The wind profiles from the five vapor trails listed in Table I are given in Figures 1 through 10. The wind speed and direction of transport are plotted separately for each profile. The twilight trails furnish data over a height range 85 to 170 km as shown in Table I. Observations can continue in the evening until the sun sets at that altitude or until the sky becomes too bright in the morning. Thus, some trails may be observed constantly for up to 15 minutes.

The TMA trails allowed determination of the winds from 92 to 130 km. The observation time was less than five minutes over most of the region, although some portions persisted much longer. These trails appeared to be brighter and more persistent over a greater height range than the previous night TMA trail in June 1965. More observations are required before the reasons for the differences can be known. The variations may simply be due to an irregularity in the ejection mechanism or an apparent increase in brightness due to the improved "seeing" in a clear winter night sky. However, the observed variation in the trails may be due to a seasonal variation in the process which produces the emission or in the reacting species.

The outstanding features of the sequential wind profiles are discussed in Section IV of this report. In particular, the changes in the general pattern during the time of the observations are noted and discussed. The existence and persistence of small-scale features are also noted. These features are prominent on the direction plates as irregularities on the otherwise smooth spiral. The very small-scale features of the trail, which

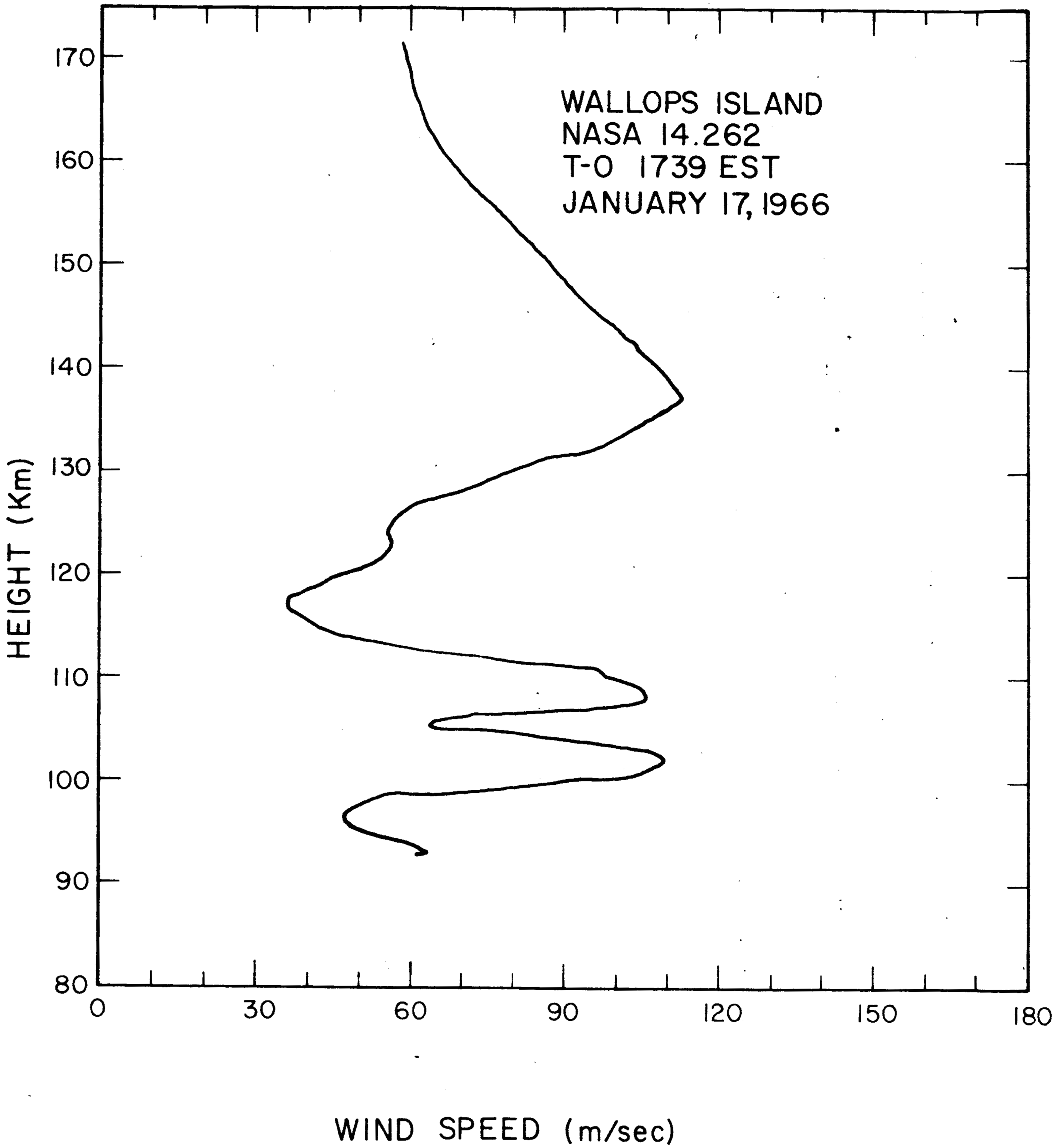
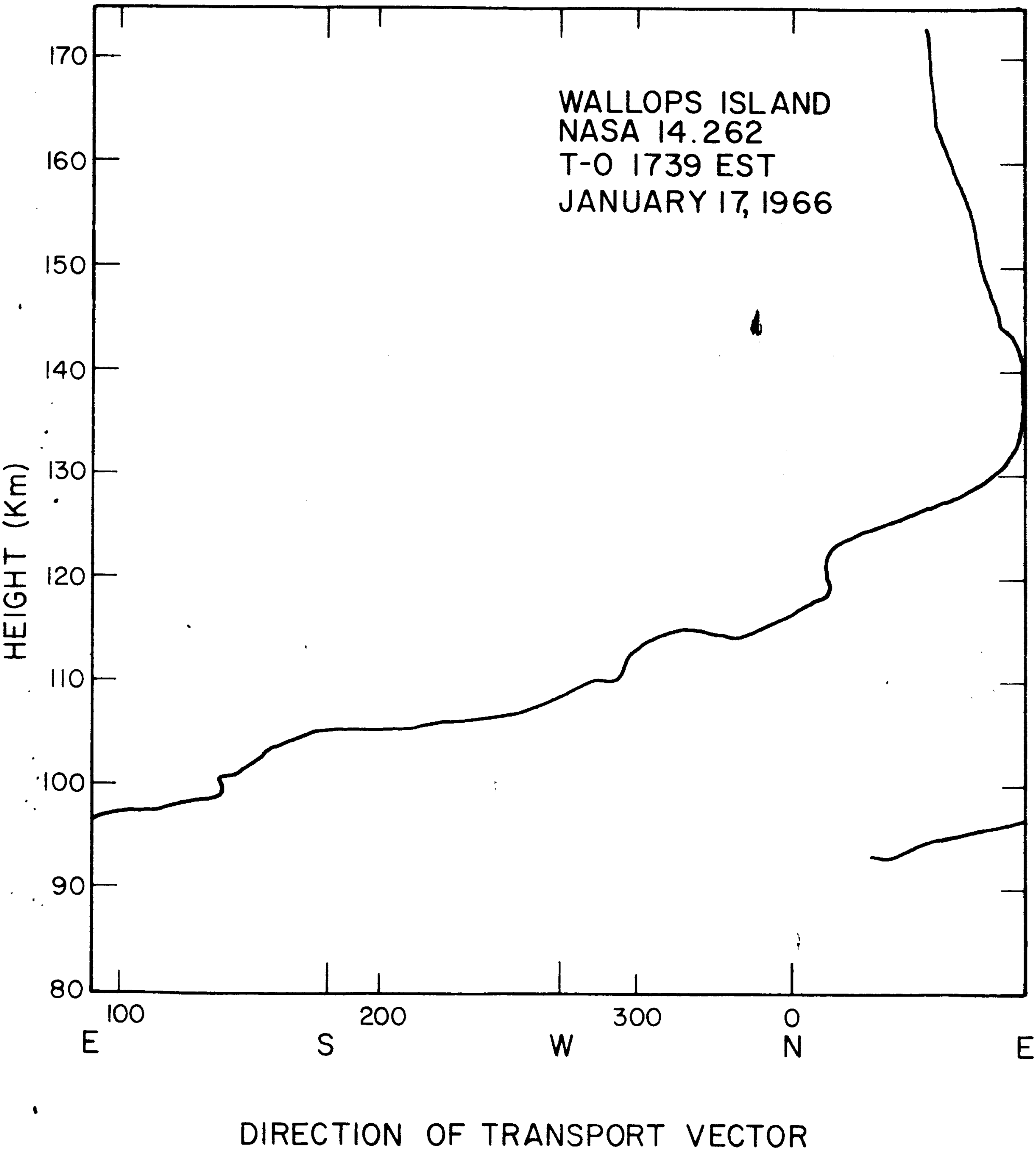
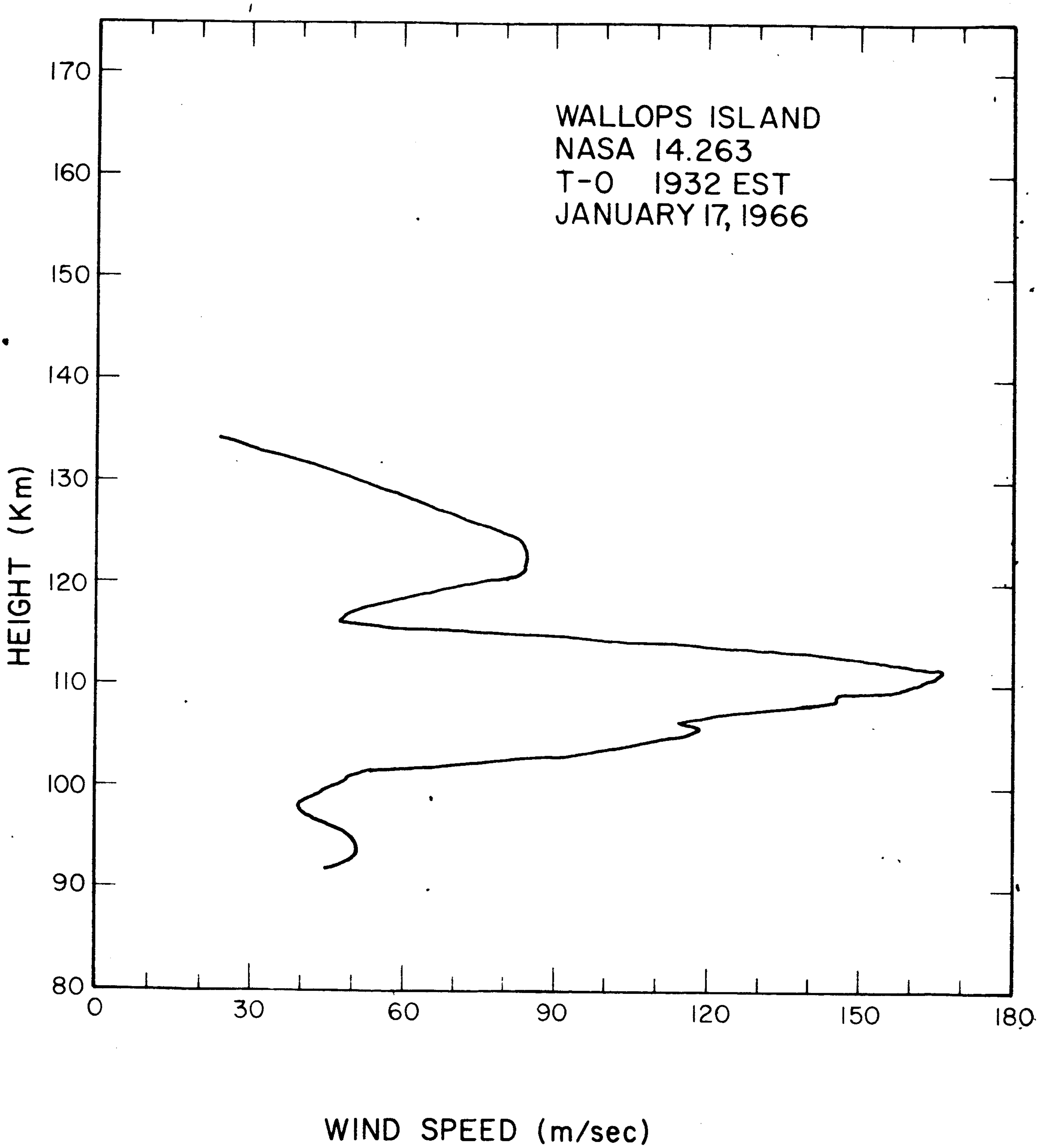

WALLOPS ISLAND
NASA 14.262
T-0 1739 EST
JANUARY 17, 1966
HEIGHT (Km)
170
160
150
140
130
120
110
100
90
80
0
30
60
90
120
150
180
WIND SPEED (m/sec)

Figure 1



WALLOPS ISLAND
NASA 14.262
T-0 1739 EST
JANUARY 17, 1966
HEIGHT (Km)
170
160
150
140
130
120
110
100
90
80
100
200
300
0
E
S
W
N
E
DIRECTION OF TRANSPORT VECTOR

Figure 2



WALLOPS ISLAND
NASA 14.263
T-0 1932 EST
JANUARY 17, 1966
HEIGHT (Km)
170
160
150
140
130
120
110
100
90
80
0
30
60
90
120
150
180
WIND SPEED (m/sec)

Figure 3

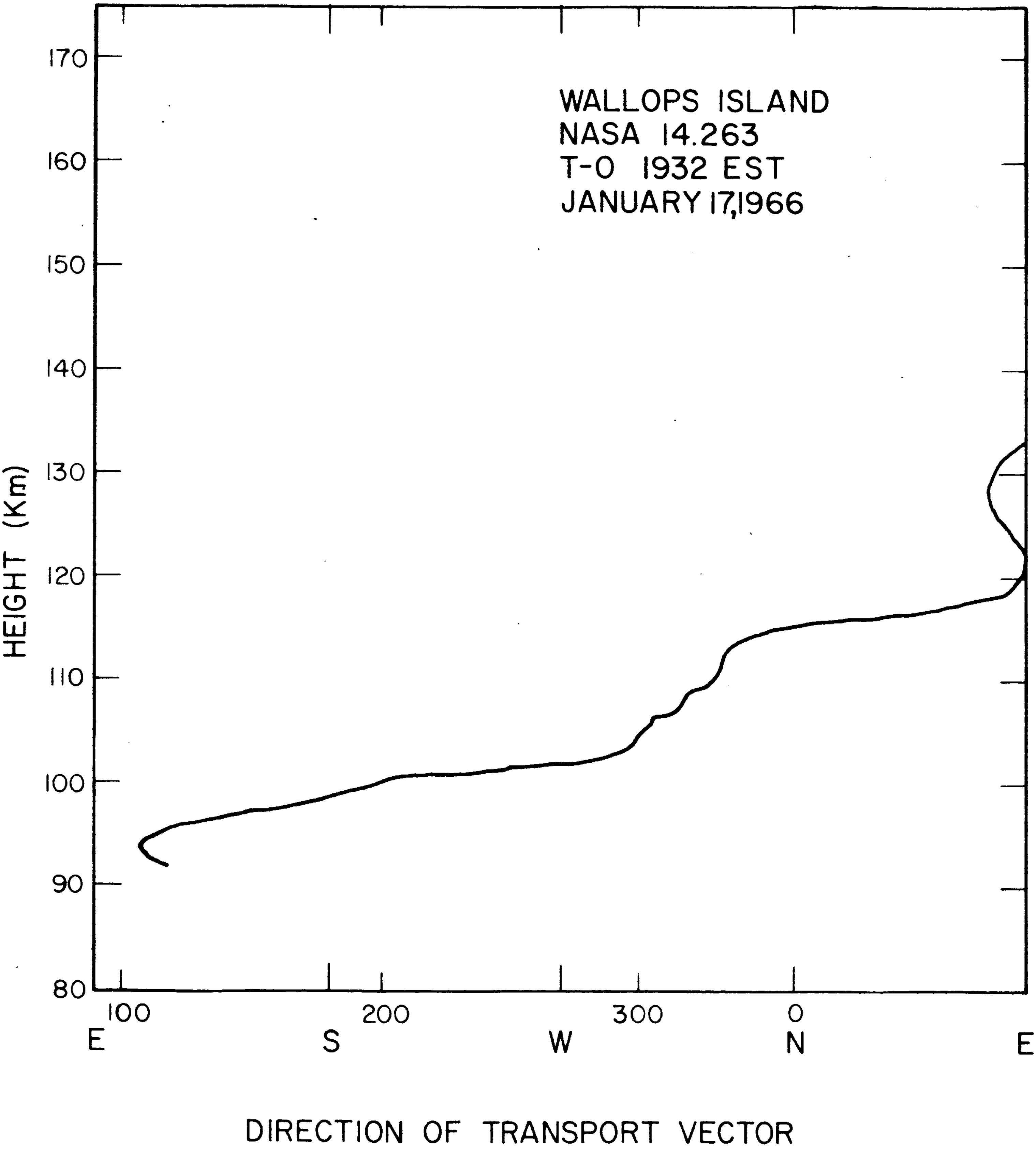

WALLOPS ISLAND
NASA 14.263
T-0 1932 EST
JANUARY 17,1966
HEIGHT (Km)
170
160
150
140
130
120
110
100
90
80
100
200
300
0
E
S
W
N
E
DIRECTION OF TRANSPORT VECTOR

Figure 4

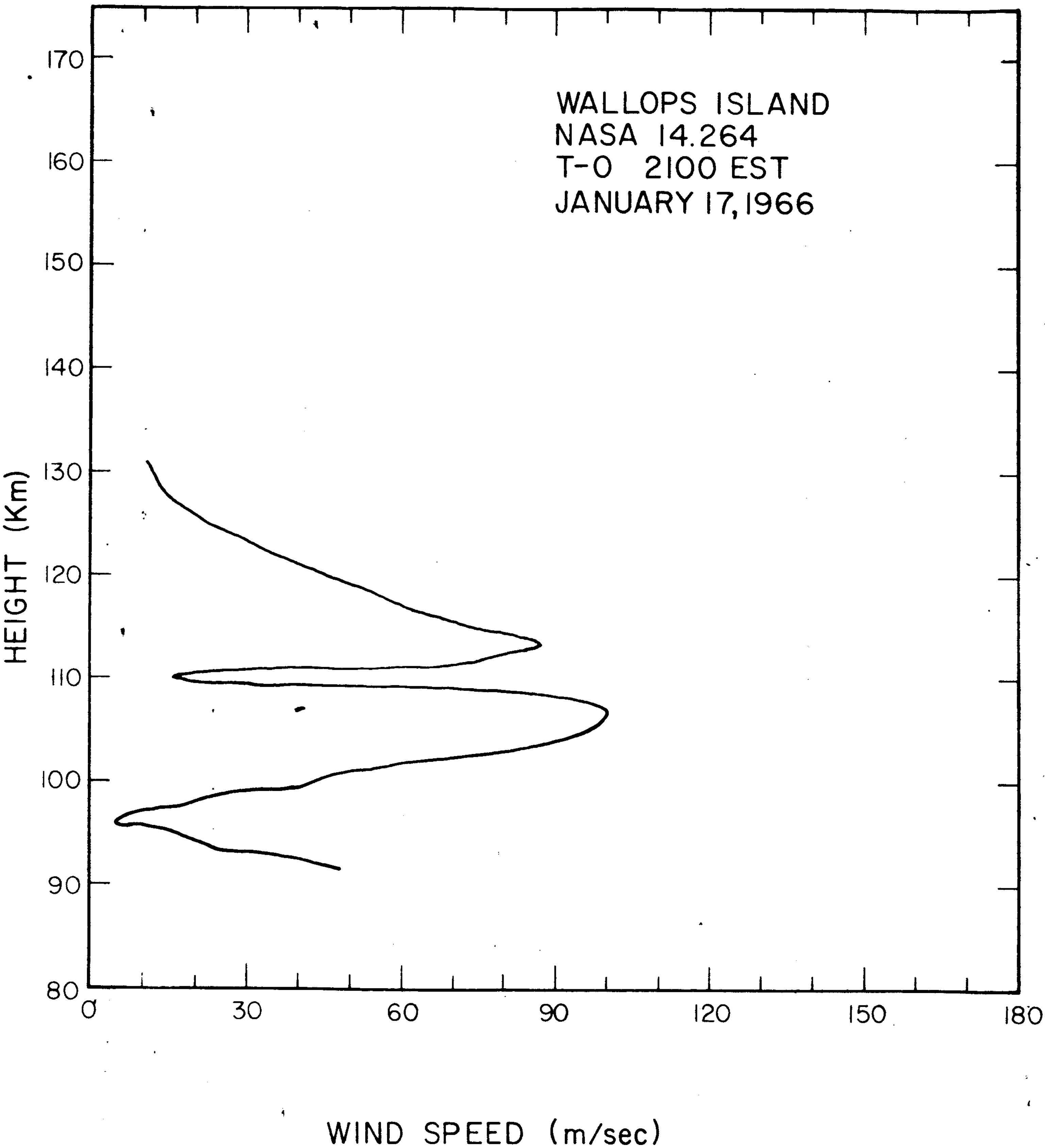

WALLOPS ISLAND
NASA 14.264
T-0 2100 EST
JANUARY 17, 1966
HEIGHT (Km)
170
160
150
140
130
120
110
100
90
80
0
30
60
90
120
150
180
WIND SPEED (m/sec)

Figure 5

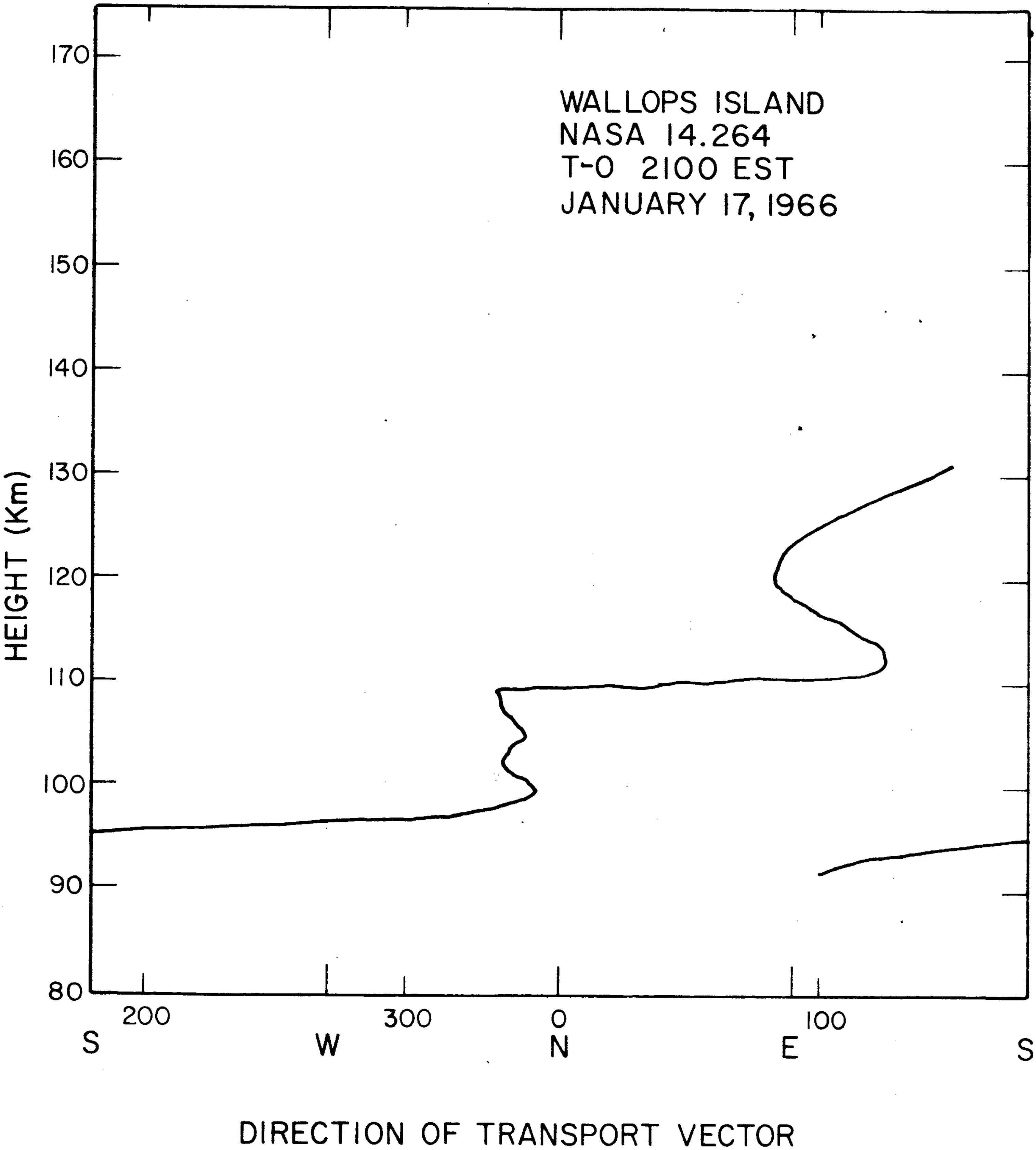

WALLOPS ISLAND
NASA 14.264
T-0 2100 EST
JANUARY 17, 1966
170
160
150
140
130
120
110
100
90
80
HEIGHT (Km)
200
300
0
100
S
W
N
E
S
DIRECTION OF TRANSPORT VECTOR

Figure 6

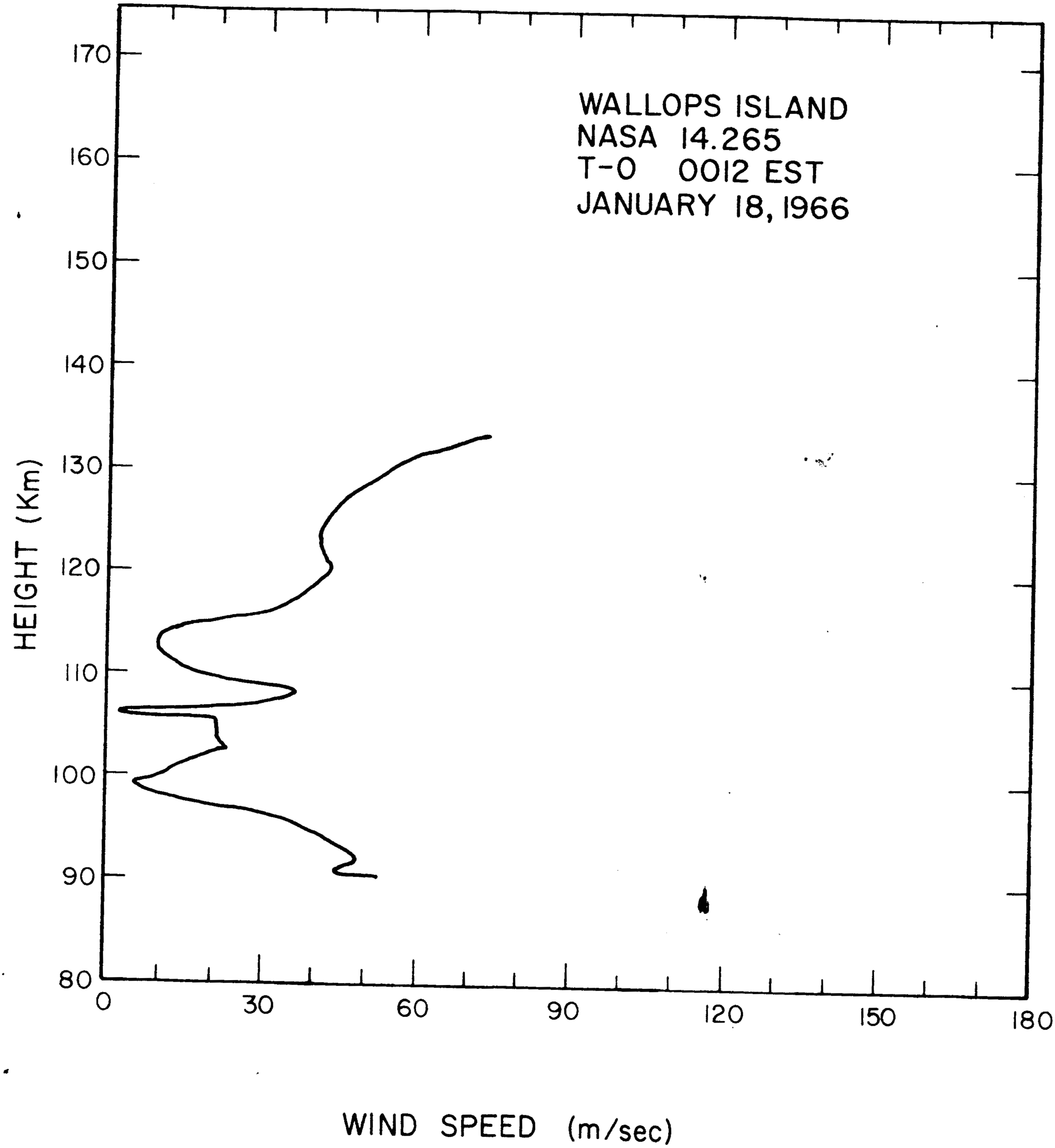

WALLOPS ISLAND
NASA 14.265
T-0 0012 EST
JANUARY 18, 1966
HEIGHT (Km)
170
160
150
140
130
120
110
100
90
80
0
30
60
90
120
150
180
WIND SPEED (m/sec)

Figure 7

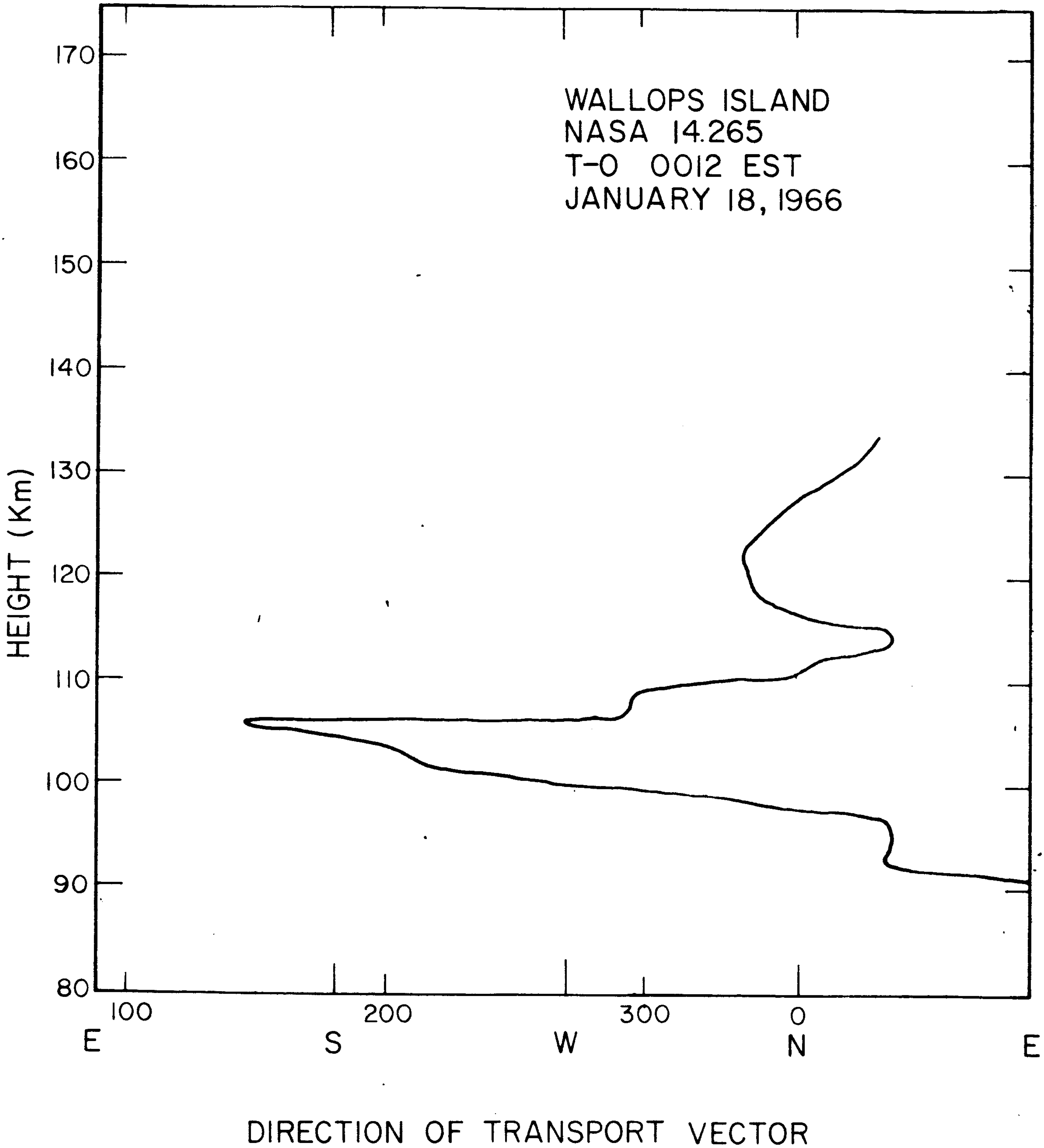

WALLOPS ISLAND
NASA 14.265
T-0 0012 EST
JANUARY 18, 1966
HEIGHT (Km)
170
160
150
140
130
120
110
100
90
80
100
200
300
0
E
S
W
N
E
DIRECTION OF TRANSPORT VECTOR

Figure 8

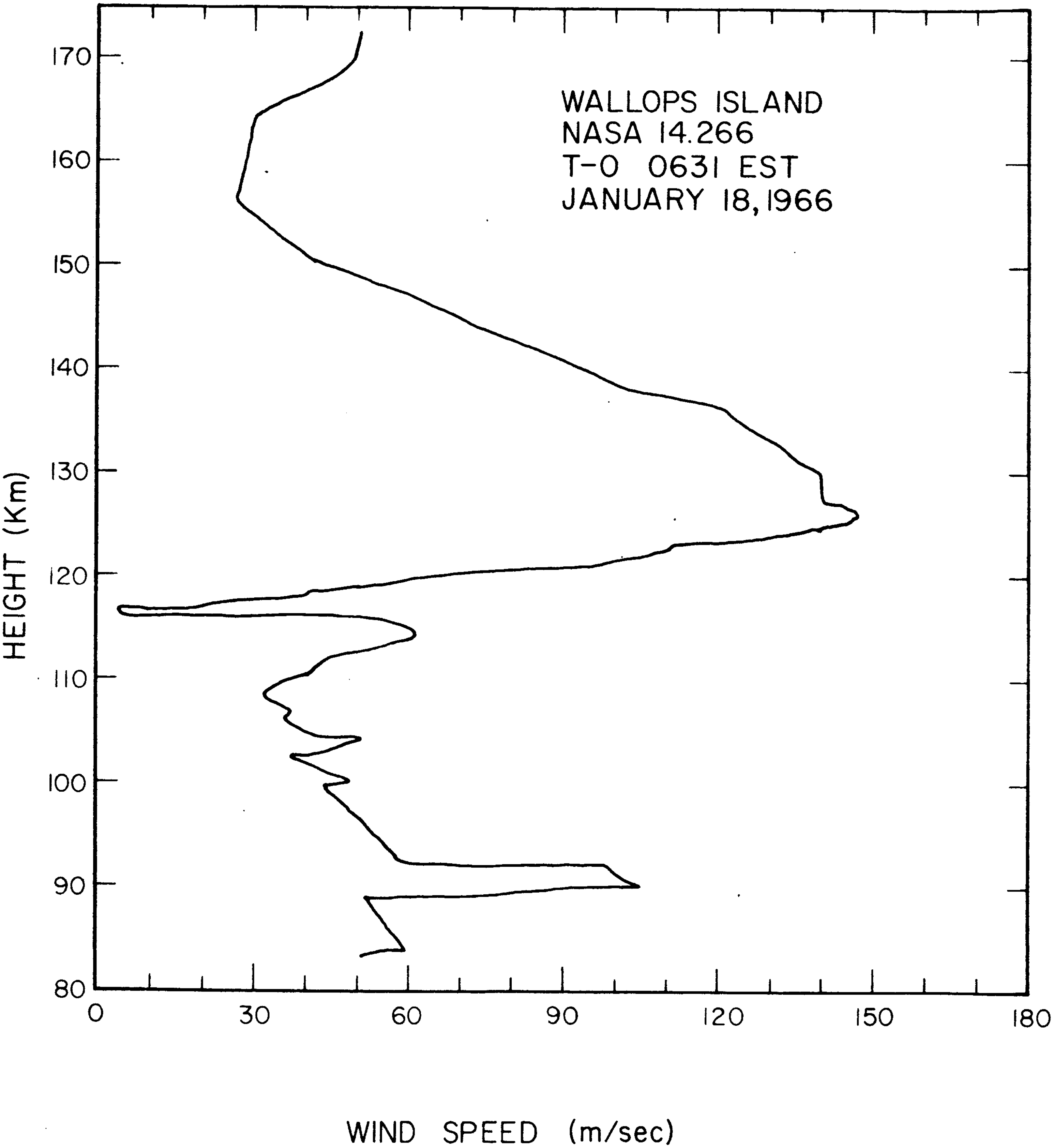

WALLOPS ISLAND
NASA 14.266
T-0 0631 EST
JANUARY 18, 1966
HEIGHT (Km)
170
160
150
140
130
120
110
100
90
80
0
30
60
90
120
150
180
WIND SPEED (m/sec)

Figure 9

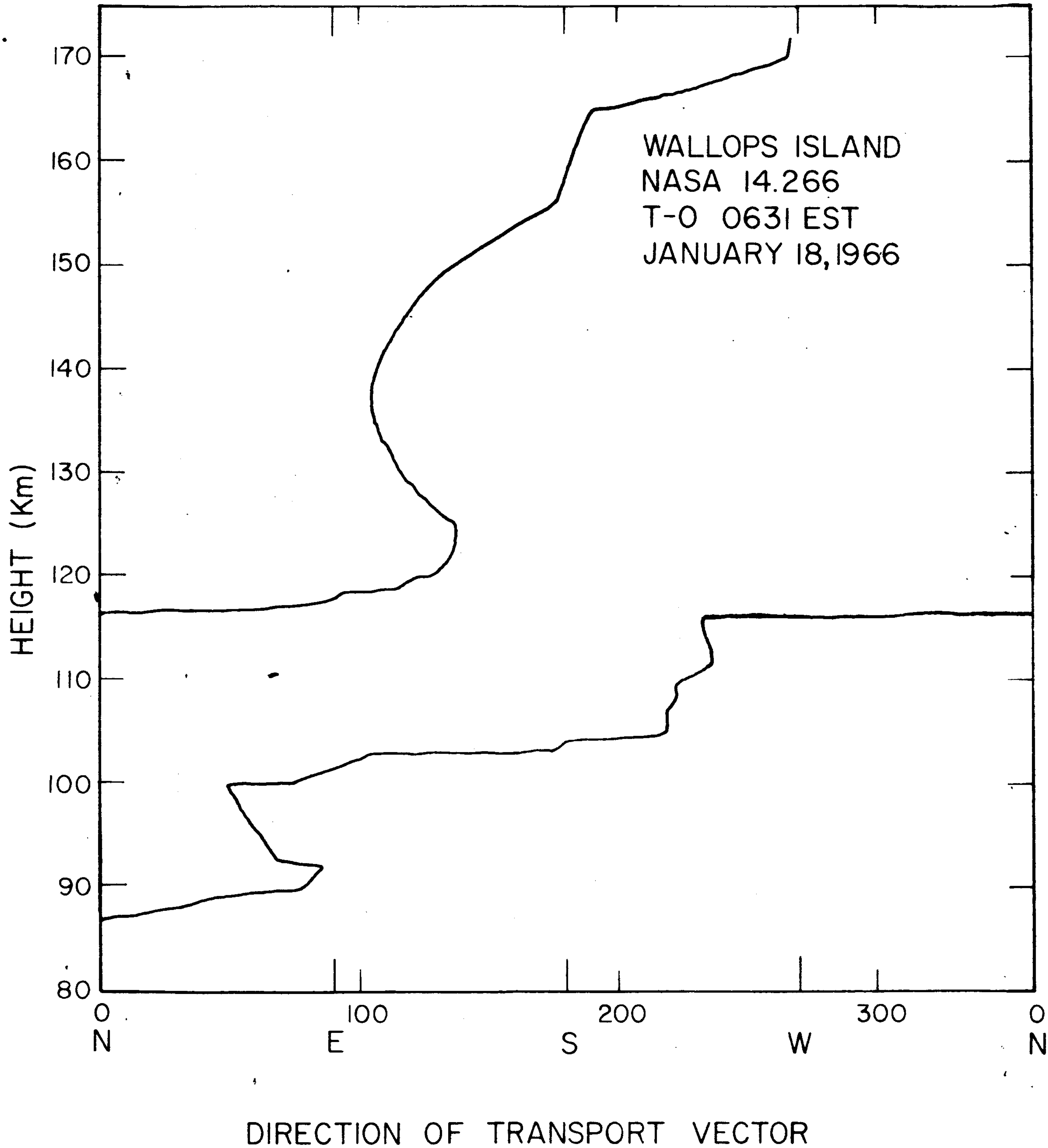

WALLOPS ISLAND
NASA 14.266
T-0 0631 EST
JANUARY 18, 1966
HEIGHT (Km)
170
160
150
140
130
120
110
100
90
80
0
100
200
300
0
N
E
S
W
N
DIRECTION OF TRANSPORT VECTOR

Figure 10

are sometimes referred to as "turbulent", are not discussed in this report. Good photographs of this region were obtained and will be analyzed. Previous analysis[1] of the Wallops Island data have shown that this very small-scale structure does not have the appearance of turbulence, does not expand according to accepted turbulence theory, and is not directly associated with wind shear as is expected of turbulence.

IV. CHARACTERISTIC TIMES FOR WIND VARIATIONS

Until recently, the vapor trail method could only be used during twilight. Thus, wind profiles could only be obtained at about 12 hour intervals. As the number of observations increased, no diurnal or seasonal variations could be found. However, it became apparent that the same types of patterns were continually repeated but not periodically. Originally, the profiles were divided into three classes which occurred with about equal frequency at morning and evening twilight and also at each season. The group originally designated as Class I contained altitude profiles in which the winds were light at all altitudes, but the speed and direction changed rapidly with altitude. The direction of rotation of the wind vector remained the same only over small height intervals. Class II profiles exhibited at least one region of high wind speed, usually between 100 and 120 km. The direction of rotation of the wind vector with increasing height tended to be clockwise, but at least one height interval had a major reversal in direction of rotation. Class III profiles generally had large wind speeds over most of the entire height range and the direction of rotation of the wind vector with increasing height was continuously clockwise.

Since 1964, vapor trails have been used during the night at Wallops Island and sequential observations have been obtained as shown in Table II. Although the amount of data is still small, some preliminary observations can be made. The series of 14-15 July 1964 and 22-23 June 1965 show very similar variations in the general pattern throughout the night. The profile during both evening twilights could be called Class I, i.e.,

TABLE II

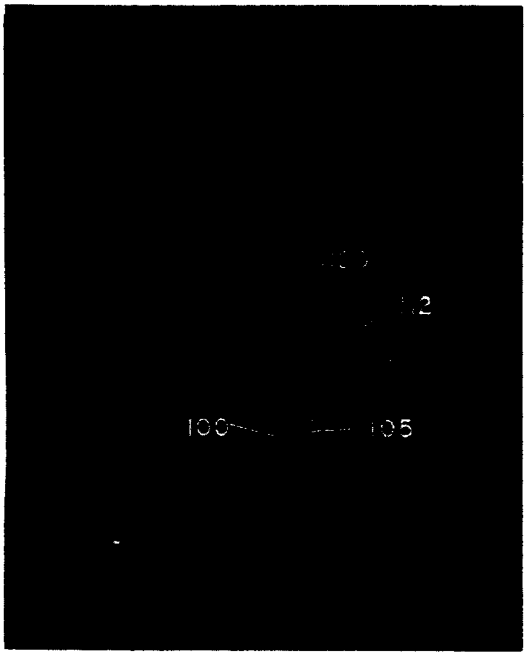
SCHEDULE OF SEQUENTIAL OBSERVATIONS
(WALLOPS ISLAND, VA.)

Date	Firing Time
15 Jan. 1964	1740 EST
16 Jan. 1964	0000
16 Jan. 1964	0640
14 July 1964	1958
14 July 1964	2309
15 July 1964	0305
15 July 1964	0406
22 June 1965	1958
22 June 1965	2300
23 June 1965	0347
17 Jan. 1966	1739
17 Jan. 1966	1932
17 Jan. 1966	2100
18 Jan. 1966	0012
18 Jan. 1966	0631

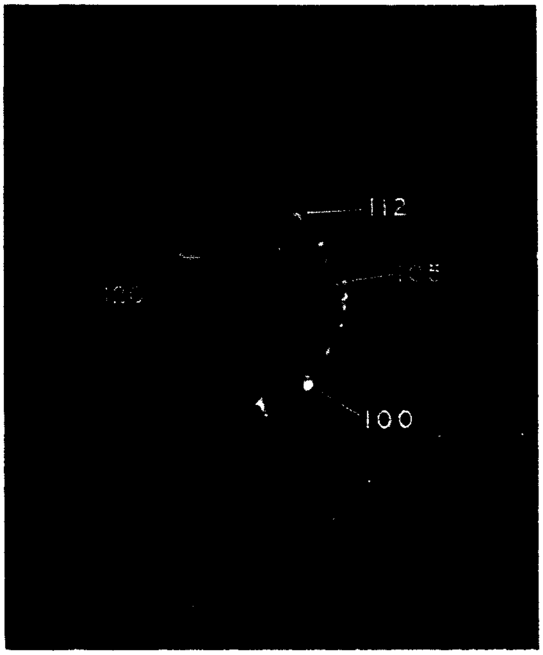
low winds which are highly variable with altitude. During the night, the wind speed increased and the large spiral pattern of Class III was formed. There is evidence of a clockwise rotation of the spiral pattern, and the time required to progress from the small-irregular pattern to the large spiral is at least 6 hours. A similar time variation was reported by Rosenberg[2] from four vapor trails at Eglin AFB, Florida during the night of 3 December 1962.

The most recent series in January 1966 at Wallops Island had more closely spaced firings than those of the previous series at Wallops and thus contains the most information. The wind profile at evening twilight was a large open spiral. The maximum wind speed increased slightly during the two hours before the second trail of the series, but during the following one and one-half hours, the East-West wind component diminished greatly while the North-South component did not. Thus, the outstanding characteristic of the profile at 2100 EST was a large shear around 110 km which has often been observed at this height and has been called Class II. The fourth trail of the series occurred after three hours and the North-South winds had also diminished so that the light variable structure of a Class I profile was observed. After a period of six hours, the wind speed had again increased as evidenced by the morning twilight trail. A similar collapsing wind pattern was also observed by Rosenberg[2] at Eglin during the night of 17-18 May 1963.

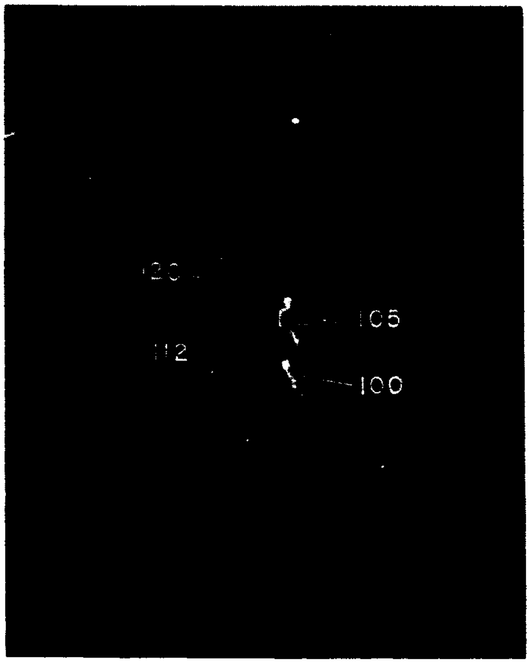
The variation of the winds during a six and one-half hour period on 17 January 1966 is shown in four successive vapor trails, Figure 11. Each photograph was taken with the same camera from the same site (Dover, Del.),



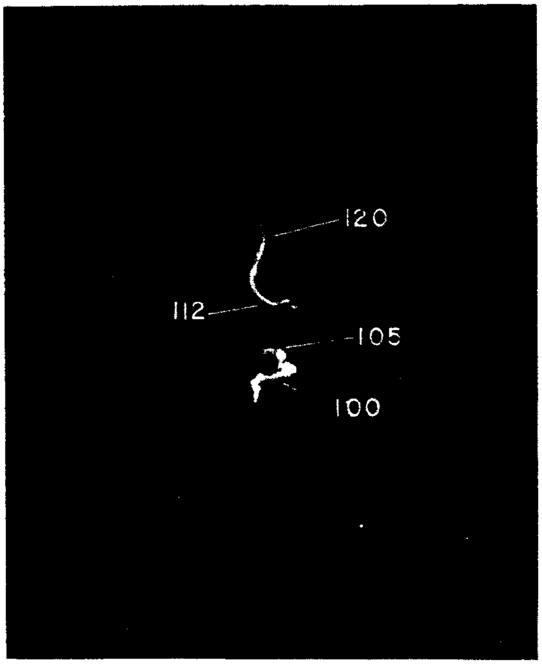
NASA 14.262 T-0 1739 EST



NASA 14.263 T-0 1932 EST



NASA 14.264 T-0 2100 EST



NASA 14.265 T-0 0012 EST

TRAIL PHOTOGRAPHS FROM DOVER, DEL. (T+3 MIN)

Figure 11

at the same time after rocket launch. All pictures are enlarged to the same scale so that the relative distortion or displacement of the trails is proportional to the wind velocity. Dover is almost due North from Wallops Island so that an East-West wind component would distort the trail to the left or right on the photographs. North-South components are evidenced by difference in the relative elevation angle of various parts of the trail. For example, a wind blowing toward the north and thus decreasing the slant range from the trail to the camera would cause that part of the trail to appear at a greater elevation angle than an adjacent region which is moving to the south, and thus increasing the slant range to the camera.

The wind pattern is thought to have evolved as follows. The trail from 14.262 at 1739 EST shows a N-S component around 100 km since the part of the trail just below 100 km is at a higher elevation than that just above. Between 105 and 107 km, there is an increasing westward component, but above 107 km the westward component decreases irregularly up to about 120 km. After two hours, the pattern, as evidenced by the trail from 14.263 at 1932 EST, had changed as follows. A large N-S component had developed as shown by the difference in elevation between 112 and 120 km. The irregular structure previously between 112 and 120 km had moved downward to 105 to 112 km. It is as if the entire profile including the small-scale irregularities had slowly moved downward and rotated clockwise providing the change from a westerly to a northerly component. At 2100 EST the trail from 14.264 shows the downward motion continuing; the N-S component still readily apparent, but the E-W component is greatly diminished. This much lower wind speed emphasizes the small, irregular structure which appears to be remaining as a lasting feature. By 0012 EST, the trail from 14.265 shows the downward motion continuing and the decrease of the N-S component as well. Apparently all that remains is the small-scale structure.

This action may be interpreted as part of a cyclic pattern in which the large spiral pattern collapsed in an orderly fashion to the small, irregular pattern in about 6 hours. This is consistent with the time for build-up of the large patterns observed from other trail sequences at Wallops Island and at Eglin. Interestingly the small-scale structure apparently has a longer period than the large winds since it appears throughout the sequence. Of course, it could be argued that the same small-scale structure does not appear on each trail. However, the similarity of shape is striking. The period of such structure would have to be much shorter than one and one-half hours in order to change completely between trails; but it would also have to be much longer than 10 minutes, during which time no change was detected in the evening twilight wind profile. It is assumed now that the small-scale structure was a lasting part of the profile which gradually moved downward. It may be observed that the velocity of downward motion is about 2 m/sec around 120 km, and about 1 m/sec or less around 100 km. This rate is below the detection limit of the method for observing times of 10 minutes but is easily and accurately observed in 90 minutes. This downward rate is in agreement with Rosenberg's observations which were interpreted as the phase velocity of a wave with a period of many hours. It is also consistent with the rate of actual mass motion of the atmosphere as suggested by Harris and Priester[(3)], if their model were extrapolated down to these heights. No indications as to which of these interpretations is correct have yet been found in the data.

V. CONCLUSIONS AND RECOMMENDATIONS

The series of vapor trails in January 1966 showed that observations spaced an hour or two apart provide much information concerning the manner in which the winds vary. The build-up or collapse of the large-scale spiral patterns require at least six hours. This time as well as the rate of downward motion of the profile is characteristic of large-scale tidal oscillations. The persistence of a wind speed of 100 m/sec for a three-hour period suggests a horizontal scale of over 1000 km.

The time variations observed at Wallops Island and at Eglin, Fla. suggest that a large-scale cyclic pattern exists. However, it has already been shown that the cyclic components are not periodic. An oscillation may appear to be periodic for a single period but not for extended times. This characteristic was first observed by the radar meteor method.(4) The cyclic components in the Wallops Island data have been termed "quasi-periodic" to emphasize this property. Since the only known driving forces with such long time correlations are tide-like oscillations which are periodic, the non-periodicity of the winds is thought to be due to the non-linear response of the atmosphere in the region.

The development of a non-linear theory is difficult but is likely to be essential to the understanding of the atmospheric circulation above 100 km. The information obtained from properly spaced sequential observations promises to be very helpful in the development of such a theory. For instance, the large spiral pattern of 17-18 January at Wallops Island did not gradually reduce in speed at a uniform rate until the small irregular profile remained.

Instead, the E-W component of the wind diminished greatly before a noticeable decrease in the N-S component occurred. Then the N-S component decreased to a very small value. A process very similar to the reverse of this was observed at Eglin on the night of 3 December 1962. More sequential observations are required to determine if such a growth pattern is the usual method of change. More sequential observations are also required for the understanding of the apparently long-lasting character of the smaller scale irregularities in the wind pattern.

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